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ASSESSMENT OF EUROPEAN RESEARCH PROGRAMS SUPPORTING COASTAL OCEAN FORECASTING SYSTEMS

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Abstract

This newsletter is a shortened version of a report that provides a review of elements of European R&D programs that are supporting operational coastal ocean forecasting systems, with an emphasis towards those programs that either attempt *coupling* between types of ocean models or that *assimilate data* in the forecast methodology. *Coupling* makes direct connections between meteorological, wave, tide/surge and/or circulation models (which, historically, have been run independently), and *data assimilation* introduces observations of the forecast variables into the forecasting model. These techniques are being explored in the MAST programs entitled European Coupled Atmosphere-Wave-Ocean Model (ECAWOM) and PRe-Operational Modelling In the Seas of Europe (PROMISE), where a common overall objective is to improve the accuracy of operational forecasts for ocean waves, water levels, and/or circulation. This newsletter provides an overall introduction to the topic, a summary of the goals of these R&D programs, and a summary of my observations and recommendations formulated as a result of discussions with some of the participants. In addition to the sections in this newsletter report, a longer written report provides more details on the types of models that are operational and under development, their various coupling and assimilation modes, and an assessment of their progress.

Introduction

The objective of this study is to review several of the research programs that are being conducted in Europe that have the common goal of providing enhancements to their coastal ocean forecasting systems. These countries have made a huge investment in understanding the water level, waves and currents in the nearby seas, and they have developed an extensive range of operational forecasting systems to provide accurate predictions of these quantities for a wide spectrum of customers. It was recognized some years ago that these systems have no equal in the US, and that the many years of experience in operating them are invaluable, so they were reviewed exhaustively in 1992-1993 in a study undertaken by ONR Europe [1-3].

The primary reason why these systems were constructed and are operated on a continuous basis is the threat of floods and high waves during storms, so the primary customer has been those agencies associated with coastal defenses. However, they also provide useful products for

everyday shipping (such as high and low water levels for ship movements into and out of harbors), search and rescue strategy, and waves and currents for the offshore energy production and construction industries. Although these systems are reasonably accurate, they have a number of limitations, so there are sizable ongoing R&D efforts that have the common goal of upgrading their accuracy. These R&D efforts are of direct interest to the US Navy because they represent state-of-the-art knowledge concerning the most important physics, numerics and implementation details for providing accurate forecasts of these important quantities in coastal regions.

The operational wave forecasting systems are based on the products of the very successful Wave Model Development and Implementation (WAMDI) Group, whose active participation was mostly European, that developed an advanced methodology for making surface wave forecasts. The WAM Cycle 4 model is implemented at the European Centre for Medium-Range Weather Forecasts (ECMWF), and versions of the model are operated at several of the member countries' meteorological forecasting centers. It is well known that these forecasting systems have significant limits on the accuracy of their predictions, so there have been a number of efforts to develop and implement improvements. Also, water level and current predictions are provided by operational tide-surge forecasting systems, but these products also have limitations in their accuracy, so the forecasting centers and other government, industrial and academic institutions are developing and implementing a number of improvements.

The 1992-93 ONR Europe study exhaustively assessed the operational aspects of these forecasting systems, with the conclusion that the capabilities of the European countries around the North Sea were excellent, and their experience in operations judged to be exceptional and having no equal in U.S. operational capabilities. Although a version of the WAM system is operated by the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) to provide wave forecasts to the fleet, it does not focus on the coast, and neither the U.S.Navy nor the civilian U.S. environmental communities have a comparable comprehensive suite of coastal forecast products. The previous study focused on the operations and the customer base, and to a lesser extent on the methodologies that are used in the models. Although there were and continue to be active research and development projects whose purposes are to advance the capabilities of these operational systems, these projects were given only cursory attention in that review because of the magnitude of the task of covering the operational aspects. These systems have not changed significantly beyond the expected evolution over the last few years, but there have been intensive R&D efforts with the common goal of improving the forecast accuracies. Thus, having largely overlooked these R&D efforts previously, the purpose of this present study is to focus on several of them, with attention given to the specific new methodologies and some of the results found to date.

As a specific example, the previous study identified a proposal to the European Union under the Marine Science and Technology (MAST) Program called the European Coupled Atmosphere-Wave-Ocean Model (ECAWOM) as being of special interest because it had the potential of further advancing their model capabilities. This proposal subsequently was funded, and it is led by Prof. Klaus Hasselmann of the Max-Planck-Institüt für Meteorologie (MPI) in Hamburg, Germany, with considerable collaboration with other European centers of excellence,

many of which were primary contributors to their present WAM forecasting systems. The primary objective of ECAWOM is the development of an advanced, *coupled* forecast model for waves and associated atmospheric and oceanic variables that *assimilates* in the model various sources of periodic observations of the forecast variables.

Another European R&D program of specific interest is the PRe-Operational Modelling In the Seas of Europe (PROMISE) Program. This program includes many of the organizations that have developed the operational systems, and its technical objectives are to rigorously evaluate existing models and the associated data for initializing, forcing and verifying them. The term *pre-operational* was coined to relate to models that are operational in principle, but which are used specifically for R&D studies, that is, run in a hindcast mode.

The progress in these and other European programs are important at this time for several reasons. First, these groups of researchers comprise the best in this area in Europe. These same Principal Investigators in ECAWOM were responsible for the WAM model that has been so successfully operated at many forecasting centers, and those in PROMISE were responsible for developing and testing many of the operational tide-surge and wave models. Thus, their new results on the work in these programs can be expected to provide us with important information prior to their ultimate publication that we should consider in planning and implementing our R&D projects in this area. Certainly, their large commitment to the important scientific, technological and operational issues can be expected to provide valuable information on what is important and what is not so important in the way of providing significant improvements, just as they did during their intensive effort during the development of WAM.

Second, this topic is of increased interest to the U.S. Navy because of perceived limited capabilities for providing accurate forecasts along foreign coastlines. This need is heightened by the increasing dependence of the performance of our modern weaponry on the environment in which these systems must operate. The coastal ocean and atmosphere are particularly difficult to forecast because of the comparatively small time and space scales of variability relative to those in the open ocean, due to the strong influence of the atmosphere-ocean-land interfaces that have large horizontal gradients. Of great importance to us, the area of interest, unfriendly defended coastlines, is not easily accessible with *in situ* operational monitoring systems, so the development of appropriate models and of data assimilation schemes (preferably based on data from remote sensing) on which to base forecasting systems is a necessary step that U.S. Navy researchers must take in this area. As a specific example of the difference between the European approach and our needs, shoaling wave models are used to propagate wave forecasts into shallow water, but these models depend upon knowledge of the bathymetry, and the Europeans have ready access to this information from recent surveys. The U.S. Navy, on the other hand, does not have access to recent data on the bathymetry along stretches of foreign coastlines, so an appropriate model must incorporate the water depth as a forecast variable. These differences notwithstanding, the many aspects of coastal ocean predictions are common, and the lessons the Europeans are learning in their R&D programs are of great interest to us.

Thus, the purpose of this report is to provide an assessment of the goals, progress and

potential breakthroughs of several of these European research programs, and to communicate these with the U.S. Navy and other interested U.S. government R&D and operational forecasting communities. Many of the those in the target audience of this review are aware of these European groups, but the specific organizations and points of contact for this review are provided in appendices for those that might find them useful.

The ECAWOM Proposal Goals and Plan

The two primary goals for ECAWOM are to:

1) integrate a number of ongoing projects in European institutions on coupled models to produce a new joint state-of-the-art model, and use it as a common tool for studying improved physics and numerics for a wide variety of applications, and

2) coordinate ongoing efforts in the use of satellite data (primarily from ERS-1&2) for deriving wind and wave fields, and their optimal use along with conventional data for assimilation in the model.

The Principal Investigators include the best of Europe: Prof. Hasselmann as mentioned previously, Dr. Gerbrand Komen of KNMI in De Bilt, The Netherlands, Prof. Werner Alpers of the Institüt für Meereskunde in Hamburg, Dr. Roger Flather of the Proudman Oceanographic Laboratory in Liverpool, and Dr. Peter Janssen presently with ECMWF in Reading. Altogether, a total of fourteen institutes are participating.

The plan for ECAWOM, as per the original proposal to MAST in 1992/1993 (and reported in [1-3] in 1993), was to have four modeling and four data components of the project. The modeling effort was to develop, calibrate and test the sensitivity of a coupled atmosphere-wave-ocean model system. This effort was to begin by coupling existing atmospheric, wind wave and ocean models and concentrate on a consistent coupling between the atmosphere and the ocean through the detailed description of the interactions at the interface, and to migrate the results in three years to a joint European Operational Model Prediction System. An initial development was to couple the WAM cycle 4 model that presently is operational at ECMWF with the Scandinavian-Dutch-Irish High Resolution Limited Area atmospheric Model (HIRLAM) through a sea-state-dependent parameterization of the surface roughness. This was expected to incorporate free response of the atmospheric boundary layer through parameterizations based on numerical solutions of the nonlinear boundary-layer/surface-wave equations. The coupling of WAM to the ocean model was expected to be based on the wave momentum and mass flux source terms in the ocean momentum and continuity equation using a parameterization of entrainment in the mixed layer. This was to be followed by a coupling of WAM to the present storm-surge model and an undetermined 3-D ocean circulation model, and the coupled models tuned for European regional seas. The data sub-project was planned to be comprised of algorithm development (primarily improvement of ERS-1and -2 parameter extraction algorithms, although as funded, this task was deleted), data assimilation, development of advanced techniques for

model tuning and validation, and validation of the coupled model.

The PROMISE Proposal Goals and Plans

The primary goals of this project are to examine the many parameters that exist in the various ocean forecasting models for water depth, currents, waves, turbulence, and sediments. The primary problem to be addressed is the choice of the parmeterizations, the choice of values of the specific parameters, and the coupling between different models. This includes, for example, the numerics, the resolution and the range of processes included. Although there is interest in improving the basic understanding of the physical processes, the focus is to support better formulation of predictive models, and subsequently better management effectiveness of European seas. Work focuses on optimizing the application of existing pre-operational dynamical models of the North Sea by determining the dependency on the resolution, range of processes incorporated, and associated numerics. The plan is to assemble four (or more) comprehensive observational data sets relating to the appropriate dynamics and associated sedimentary processes, and to rationalize the existing tidal, storm, turbulence and wave models in locations of extensive experience with existing monitoring networks.

Conclusions and Recommendations

Considering the reasonable capabilities of these systems when reviewed four years ago, I was not surprised to find that the advances have been evolutionary. There continues to be an amazingly active and close relationship between the forecasting centers, the users and the R&D groups, and the improvements in the systems have to be judged to be incremental.

As to results to date on both coupling and assimilation, they are mixed. For global wave forecasts, comparisons of several different forecasting systems are being made by a loose collaboration of researchers (UKMO, FNMOC, ECMWF, AES, and NCEP), and it is too early to tell what works best, and what does not. For regional wave forecasts, it is clear that improvements have been made in a number of test cases of both data assimilation and coupling. Data assimilation is used in several of the systems because their tests have shown significant improvements, but coupling generally has not exhibited comparable results to date. There is a general feeling that the coupled models have not had the benefit of years of tuning and therefore should not be expected immediately to perform as well as the operational systems.

Because of the need for observations to drive the forecasting systems (and assimilating data as the case may be), there is a healthy level of interaction between the monitoring and the forecasting communities in the countries around the North Sea, including the use of remote sensing methodologies for ocean monitoring. Their results provide valuable information on what works and what doesn't, but the models do not directly apply to the USN need for systems that work in locations where monitoring systems do not exist, and there is no directly applicable work in Europe in the design and/or construction of systems that are portable, neither for the

forecasting nor the monitoring components.

Probably the single most useful thing these MAST projects accomplish is to coordinate the activities of a large number of researchers and forecasting system operators that are working in this area anyway, but otherwise more independently. The projects simply force them to talk to each other on a regular basis.

As to the issue mentioned previously about the U.S. Navy need for additional environmental fields along coastlines, such as bathymetry, I found no specific work in these R&D centers that address this. The sponsor community has not identified this as a need and, therefore, the R&D centers have not given any thought to it. The shoaling wave field is connected in a known manner with the local bathymetry, so it seems possible to integrate this field as an additional unknown into a dynamical model that assimilates remotely sensed images of the waves both for estimating the wave spectrum and the bathymetry under the waves.

There are several *recommendations* that result from this study.

1. ONR should closely monitor the comparisons of operational global wave models that presently are being carried out by researchers at several of the forecasting centers. This comparison could be made more formal (via a WMO agreement, for example) and/or it could be supported monetarily by ONR to focus the effort and accelerate the achievement of quantitative results. However, the effort likely will continue without external support and will provide some information in the future on which of the various global wave models work best, and perhaps provide understanding as to why.

2. It is apparent that there is interest on an international scale in pursuing an operational capability for regional wave forecasts, including waves in very shallow water. In light of recent new funding for the Base Enhancement on Shoaling Waves, ONR has signaled a clear interest in this area, and this could be enhanced significantly by a closer association with European scientists and institutes that have much experience and common interests in this area. A closer relationship should be fostered by planning and supporting a modest international workshop in the area, and this could be executed by the ONR Europe office. ONR Program Managers having responsibilities in this area should attend meetings and support the activities (and perhaps even the recommendations) of the international Waves In Shallow Environments (WISE) Group.

3. The Europeans have learned a valuable lesson from their strong interactions between the forecasters, the researchers and the user communities, particularly as regards verification of results. This lesson should be emulated in the U.S. by a periodic meeting between these groups that would include briefings of the successes, observed limitations and outright failures of the operational systems. ONR should determine if there is quantitative information on the performance of these systems, particularly for the coastal ocean, and, if it turns out to be limited in scope or value, ONR should foster working groups, periodic meetings, and perhaps experiments that provide the data for quantitatively assessing their performance.

4. The European systems are applied to waters where the bathymetry is known relatively accurately, yet the U.S. Navy has the situation along defended coastlines where the bathymetry is one of the unknowns. Thus, there is a need for research in the U.S. Navy for stronger interactions between the shallow water modeling and remote sensing communities, with the goal to provide a modeling capability that includes water depth as one of the forecast variables. ONR should take the lead in this area by formulating a strong interaction between relevant program codes.

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Appendix I -- Relevant Home Pages

Institute/program	URL
MAST	http://europa.eu.int/en/comm/dg12/marine1.html
POL	http://www.pol.ac.uk/appl/srp1.html
GKSS	http://www.gkss.de/GKSS/allgemain/umwelt.html
KNMI	http://www.knmi.nl/home/comp_netw.html
UKMO	http://meto.govt.uk/
HIRLAM	http://www.knmi.nl/hirlam/.
ECMWF	http://www.ecmwf.int/
PROMISE	http://www.pol.ac.uk/promise/promise_6.html

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